

Contents

Preface *xiii*

1	Application of Organic Functional Additives in Batteries	1
1.1	Introduction	1
1.2	Fluorinated Additives	2
1.2.1	Functions of Fluorinated Additives	2
1.2.1.1	Improvement of Safety Performance	2
1.2.1.2	SEI-Forming Additives	2
1.2.1.3	High Oxidation Stability	4
1.2.1.4	Promotion of the Formation of Anion-Rich Solvation Structure	5
1.2.1.5	Reduction of Desolvation Barrier	6
1.2.2	Synergies of Fluoroethylene Carbonate with Other Compounds	6
1.2.2.1	Fluoroethylene Carbonate and Other Fluorinated Electrolytes	6
1.2.2.2	Fluoroethylene Carbonate and Lewis Base	7
1.2.2.3	Fluoroethylene Carbonate and Glyme	7
1.2.3	Drawbacks of Fluoroethylene Carbonate	8
1.2.3.1	Generation of HF Gas	8
1.2.3.2	Increase of Impedance and Loss of Impedance	8
1.2.3.3	Incompatibility with Other Electrodes	8
1.2.3.4	Recycling Issues	9
1.3	Nitro Additive	9
1.3.1	Functions of Nitro (NO_3^-)	9
1.3.1.1	Participation in Solvation and Desolvation Structures	9
1.3.1.2	Formation of Inorganic-Rich SEI	10
1.3.1.3	CEI-Forming Additives	12
1.3.1.4	Functions in Lithium–Sulfur Batteries	13
1.3.1.5	Stabilization of Water Molecules	14
1.3.2	Organic Nitro Additive	14
1.3.2.1	Complex Nitrate-Based Additives	14
1.3.2.2	Complex Nitro-Based Additives	15
1.3.3	Drawbacks and Solutions of Nitro Additives	15
1.3.3.1	Low Solubility	15
1.3.3.2	Sacrificial Additives	17

1.3.3.3	High Decomposition Activation Energy of LiNO_3	18
1.4	Nitrile Additives	19
1.4.1	Functions of Nitrile Additives	19
1.4.1.1	Plasticization	19
1.4.1.2	Facilitation of Ion Transport	20
1.4.1.3	Promotion of Lithium Salt Dissolution	22
1.4.1.4	Widening of the Electrochemical Window	22
1.4.1.5	Inhibiting the Decomposition of the Electrolyte	22
1.4.1.6	Low Flammability	22
1.4.1.7	Improvement of Polymer Flexibility	23
1.4.1.8	Modification of the Cathode Interface	23
1.4.1.9	Involvement in the Solvation Structure of Zn^{2+}	24
1.4.1.10	Weakening of Ionic Association	24
1.4.1.11	Contribution to the Formation of SEI	24
1.4.2	Compatibility Analysis of Nitrile and Lithium Metal	25
1.4.2.1	Incompatibility of Nitrile and Lithium Metal	25
1.4.2.2	Improvement of the Compatibility of Nitrile and Lithium Metal	25
1.4.3	Other Drawbacks of Nitrile Additives	28
1.4.3.1	Low Mechanical Strength	28
1.4.3.2	Prone to Polymerization	28
1.4.3.3	Crystallinity	28
1.5	Phosphate Ester Additives	29
1.5.1	Functions of Phosphate Ester Additives	29
1.5.1.1	Flame Retardant	29
1.5.1.2	Stabilization of Cathodes and Anodes	30
1.5.1.3	Involvement in Solvation Structure Regulation	31
1.5.2	Drawbacks of Phosphate Ester	32
1.5.2.1	Incompatibility with Anodes	32
1.5.2.2	Improvement of the Compatibility of Phosphate Ester and Lithium Metal	32
1.6	Sulfate Ester Additives	34
1.6.1	Functions of Sulfate Ester Additives	34
1.6.1.1	SEI-Forming Additives	34
1.6.1.2	CEI-Forming Additives	36
1.7	Conclusion and Outlook	39
	References	40
2	Application of Biopolymers in Batteries	51
2.1	Introduction	51
2.2	Overview of Biopolymers	53
2.2.1	Carboxymethyl Cellulose (CMC)	53
2.2.2	Chitosan (CS)	54
2.2.3	Sodium Alginate (SA)	56
2.2.4	Lignin	57
2.2.5	Gum Arabic (GA)	57

- 2.2.6 Guar Gum (GG) 59
- 2.2.7 Xanthan Gum (XG) 59
- 2.2.8 Starch 60
- 2.2.9 Gelatin 61
- 2.2.10 Tragacanth Gum (TG) 62
- 2.2.11 Cellulose (CLS) 63
- 2.2.12 Trehalose (THL) 64
- 2.2.13 Citrulline (Cit) 64
- 2.2.14 Pectin 65
- 2.2.15 Carrageenan 66
- 2.3 Application of Biopolymers in Binders 66
 - 2.3.1 Carboxymethyl Cellulose 67
 - 2.3.2 Chitosan 68
 - 2.3.3 Sodium Alginate 70
 - 2.3.4 Lignin 72
 - 2.3.5 Gum Arabic 74
 - 2.3.6 Guar Gum and Xanthan Gum 75
 - 2.3.7 Starch 75
 - 2.3.8 Gelatin 76
 - 2.3.9 Tragacanth Gum (TG) 78
- 2.4 Application of Biopolymers in Electrolytes 79
 - 2.4.1 Cellulose 79
 - 2.4.2 Chitosan 81
 - 2.4.3 Lignin 82
 - 2.4.4 Gelatin 85
- 2.5 Application of Biopolymers in Electrolyte Additives 87
 - 2.5.1 Cellulose 88
 - 2.5.2 Trehalose 88
 - 2.5.3 Citrulline 89
 - 2.5.4 Pectin 90
- 2.6 Application of Biopolymers in Separators 90
 - 2.6.1 Cellulose 91
 - 2.6.2 Starch 94
 - 2.6.3 Carrageenan 95
- 2.7 Application of Biopolymers in Anode Functional Layers 95
 - 2.7.1 Cellulose 96
 - 2.7.2 Chitosan and Sodium Alginate 96
- 2.8 Conclusion and Outlook 98
- References 100

- 3A Application of Synthetic Polymers in Batteries: Carbon-chain Polymers 107**
 - 3A.1 Introduction 107
 - 3A.2 Overview of Synthetic Polymers Materials 107
 - 3A.2.1 Polyvinylidene Difluoride (PVDF) 108

- 3A.2.2 Polytetrafluoroethylene (PTFE) 109
- 3A.2.3 Styrene-Butadiene Rubber (SBR) 110
- 3A.2.4 Polyvinyl Alcohol (PVA) 111
- 3A.2.5 Polyacrylics (PA) 111
- 3A.2.6 Polyacrylonitrile (PAN) 112
- 3A.2.7 Polyvinyl Pyrrolidone (PVP) 113
- 3A.2.8 Polyolefin (PO) 114
- 3A.3 Application of Synthetic Polymers in Binders 115
 - 3A.3.1 Polyvinylidene Difluoride 115
 - 3A.3.2 Polytetrafluoroethylene 117
 - 3A.3.3 Styrene-Butadiene Rubber 118
 - 3A.3.4 Polyvinyl Alcohol 119
 - 3A.3.5 Polyacrylics 122
- 3A.4 Application of Synthetic Polymers in Electrolytes 124
 - 3A.4.1 Polyvinylidene Difluoride 125
 - 3A.4.2 Polyacrylonitrile 129
 - 3A.4.3 Polyacrylics 131
 - 3A.4.4 Polyvinyl Alcohol 133
- 3A.5 Application of Synthetic Polymers in Battery Separators 135
 - 3A.5.1 Polyolefin 136
 - 3A.5.2 Polyvinylidene Difluoride 138
 - 3A.5.3 Polyacrylonitrile 139
 - 3A.5.4 Polyvinyl Alcohol 140
- 3A.6 Application of Synthetic Polymers in Anodes 142
 - 3A.6.1 Polyacrylonitrile 142
 - 3A.6.2 Polyacrylics 143
- 3A.7 Conclusions and Outlook 143
- References 145

- 3B Application of Synthetic Polymers in Batteries: Hetero-chain Polymers 155**
 - 3B.1 Introduction 155
 - 3B.2 Overview of Synthetic Polymers Materials 155
 - 3B.2.1 Epoxy Resin (EPR) 156
 - 3B.2.2 Polyethylenimine (PEI) 157
 - 3B.2.3 Polyurethane (PU) 158
 - 3B.2.4 Polyethylene Oxide (PEO) 158
 - 3B.2.5 Polyethylene Terephthalate (PET) 159
 - 3B.2.6 Polyimide (PI) 160
 - 3B.3 Application of Synthetic Polymers in Binders 161
 - 3B.3.1 Epoxy Resin 161
 - 3B.3.2 Polyethylenimine 162
 - 3B.3.3 Polyurethane 164
 - 3B.3.4 Polyimide 166
 - 3B.4 Application of Synthetic Polymers in Electrolytes 167

- 3B.4.1 Epoxy Resin 167
- 3B.4.2 Polyurethane 170
- 3B.4.3 Polyethylene Oxide 173
- 3B.4.4 Polyimide 176
- 3B.5 Application of Synthetic Polymers in Battery Separators 178
- 3B.5.1 Polyethylene Terephthalate 178
- 3B.5.2 Polyimide 179
- 3B.6 Conclusions and Outlook 180
- References 182

- 4 Application of Nontraditional Organic Ionic Conductors in Batteries 189**
- 4.1 Ionic Liquids 189
 - 4.1.1 Introduction of Ionic Liquids 189
 - 4.1.2 Development of Ionic Liquids 190
 - 4.1.3 Catalog of Ionic Liquids 191
 - 4.1.4 Advantages of Ionic Liquids for Batteries 193
 - 4.1.5 Synthesis and Characterization Method of Ionic Liquids 193
 - 4.1.6 Application of Ionic Liquids 194
- 4.2 Application of ILs in Batteries 196
 - 4.2.1 Ionic Liquid Electrolyte 198
 - 4.2.2 Ionic Liquid/Organic Solvent Electrolyte 206
 - 4.2.3 Organic–Inorganic Composite Ionic Liquid Electrolyte 210
- 4.3 Single-Ion Conductive 215
 - 4.3.1 Introduction of Single-Ion Conductive 215
 - 4.3.2 Catalog of Single-Ion Conductive 216
- 4.4 Application of Single-Ion Conductive in Batteries 217
 - 4.4.1 Organic Single-Ion Conductor Electrolyte 217
 - 4.4.2 Organic–Inorganic Composite Single-Ion Conductor Electrolyte 225
- 4.5 Conclusions and Outlook 228
- References 230

- 5 Application of Self-Healing Materials in Batteries 239**
- 5.1 Introduction 239
 - 5.1.1 The Need for Battery Innovation 239
 - 5.1.2 Overview of Self-Healing Materials 239
 - 5.1.3 Benefits of Self-Healing Technologies in Batteries 240
 - 5.1.4 Challenges in Scaling and Commercializing Self-Healing Materials 242
- 5.2 Types of Self-Healing Materials for Battery Applications 243
 - 5.2.1 Physically Bonded Self-Healing Materials 243
 - 5.2.2 Chemically Bonded Self-Healing Materials 243
 - 5.2.3 Composite Self-Healing Materials with Multiple Repair Mechanisms 244
- 5.3 Applications of Self-Healing Materials in Batteries 244
 - 5.3.1 Gel Polymer Electrolytes 244

5.3.2	Solid Polymer Electrolytes	256
5.3.3	Composite Electrolytes	272
5.3.4	Electrode Binders	275
5.4	Conclusions and Outlook	281
	References	282
6	Application of Low-Dimensional Materials in Batteries	287
6.1	Introduction	287
6.1.1	Lithium-Metal Batteries	287
6.1.2	Low-Dimensional Composite Materials	288
6.2	Low-Dimensional Composite Cathode Materials	289
6.2.1	Composite Methods for Low-Dimensional Cathode Materials	290
6.2.2	One-Dimensional Materials in Cathode	293
6.2.2.1	Carbon Nanotube (CNT) Materials	293
6.2.2.2	Carbon Nanofiber (CNF) Materials	297
6.2.3	Two-Dimensional Materials in Cathode	299
6.2.3.1	Graphene Materials	299
6.2.3.2	MXene Materials	304
6.3	Low-Dimensional Composite Materials in Separators	309
6.3.1	Zero-Dimensional Materials in Separators	310
6.3.2	One-Dimensional Materials in Separators	312
6.3.3	Two-Dimensional Materials in Separators	315
6.4	Low-Dimensional Composite Current Collectors	320
6.4.1	Design of Current Collector	320
6.4.2	Nanocomposite Current Collectors	322
6.5	Low-Dimensional Composite Anode Materials	324
6.5.1	Formation of SEI and Failure Mechanism	324
6.5.2	Nanocomposite Lithium Metal Anodes	325
6.5.3	Low-Dimensional Materials in 3D-Printing Anodes	328
6.6	Conclusion and Outlook	329
	References	330
7	Applications of Porous Organic Framework Materials in Batteries	339
7.1	Introduction	339
7.1.1	Overview of Energy Demand and Battery Technologies	339
7.1.2	Limitations of Traditional Battery Material	339
7.1.3	Potential of Porous Organic Framework Materials for Energy Storage	340
7.2	Types of Porous Organic Framework Materials	341
7.2.1	Metal-Organic Frameworks (MOFs)	341
7.2.1.1	Types of MOFs	342
7.2.2	Covalent Organic Frameworks (COFs)	342
7.2.2.1	Types of COFs	343
7.2.3	Hydrogen-Bonded Organic Frameworks (HOFs)	343

7.2.3.1	Types of HOF	343
7.3	Applications of Porous Organic Framework Materials in Batteries	345
7.3.1	Applications in Electrode Materials	345
7.3.1.1	MOF as Electrode Materials	345
7.3.1.2	COF as Electrode Materials	352
7.3.1.3	HOF as Electrode Materials	356
7.3.2	Applications in Electrolytes and Electrolyte Additives	359
7.3.2.1	MOF as Electrolytes and Electrolyte Additives	359
7.3.2.2	COF as Electrolytes and Electrolyte Additives	364
7.3.2.3	HOF as Electrolytes and Electrolyte Additives	367
7.3.3	Applications in Catalysts and Catalyst Supports	368
7.3.3.1	MOF as Catalysts and Catalyst Supports	368
7.3.3.2	COF as Catalysts and Catalyst Supports	371
7.3.3.3	HOF as Catalysts and Catalyst Supports	373
7.3.4	Applications in Battery Separators	374
7.3.4.1	MOF as Battery Separator	374
7.3.4.2	COF as Battery Separator	378
7.3.4.3	HOF as Battery Separator	380
7.4	Conclusion and Outlook	381
7.4.1	Conclusion	381
7.4.2	Outlook	382
	References	383
	Index	389